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## Photo-induced changes in quality attributes of potato tubers during storage

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### Summary

The retail display of potato tubers is carried out in supermarkets under additional light sources to impart aesthetic value and consumer's attention, however, is associated with potato greening and associated disorders. The objective of this study was to identify a most appropriate light source for potato variety 'Lady Rosetta' along with photo-induced changes in different quality parameters. Potato tubers were placed for 27 days at ambient storage ( $25 \pm 2^\circ\text{C}$ ) under different light sources i.e. blue, fluorescent, green, mercury and red along with dark storage, which also served as normal control. In general, quality parameters, such as sugars, chlorophyll, total glycoalkaloids, increase while attributes, such as starch and ascorbic acid decrease during the storage period. The initial increase followed by final decline has been observed in parameters, such as total phenolic contents and radical scavenging activity. The results showed maximum retention of different quality attributes in dark potato storage. Amongst different light sources mercury and green light retained appreciable retention of different quality parameters with non-significant difference estimated between them in most of the studied parameters. Storage of potato under fluorescent, red and blue light proved to be precarious due to skin discoloration. Overall results revealed tuber sensitivity to different colored light along with their potential storage stability in the retail markets.

**Keywords:** potato; light; quality attributes; storage stability

### Introduction

The worldwide consumption of potatoes is ascribed to its lusciousness and high nutritive value (RYTEL et al., 2005). It produces more dry matter per hectare than the major cereal crops, such as wheat, rice, etc. (GRAVOUEILLE, 1999) thus considered as an important staple crop in most parts of the world. Potatoes are a rich source of carbohydrate with starch being the key ingredient or the main form, which serves as an inexpensive source of energy (LACHMAN et al., 2001). In addition, it is also considered as good source of high-quality protein such as lysine (FRIEDMAN, 2004). Four of the six main vitamins required in our daily diet are present in potatoes, which highly indicates the nutritious importance of the crop. The predominant vitamins found in potatoes are thiamin, riboflavin, niacin and an antioxidant ascorbic acid. Ascorbic acid is vulnerable to heat and light, thus its loss during storage is considered as a major index of quality deterioration (BURLINGAME et al., 2009). In addition, potatoes are the second most imperative source of vitamin B<sub>6</sub> for the elderly who are particularly at risk of chronic diseases. Vitamin B<sub>6</sub> influences hormonal synthesis, erythrocyte production, immune modulation and central nervous system functions. In addition, it is also important for treatment of various chronic diseases, such as sickle

cell anemia, asthma, and cancer (KOLASA, 1993). Potato is low cholesterol, high potassium food with significant antioxidants potential and thus capable of protecting human beings against cardiovascular diseases and cancer (LACHMAN et al., 2000). Polyphenols, in addition, are the most common dietary antioxidants (LACHMANN et al., 2008) being efficient as reducing agents, metal chelators and reactive oxygen species quenchers in a biological system.

It is impossible to prevent potato tubers from light exposure during the marketing chain and commercial processing. The response, however, presents remarkable changes in the physiology of the potato tuber and deteriorates its quality by cold sweetening, sprouting or tuber greening due to excessive chlorophyll accumulation and formation of toxic steroidal glycoalkaloids (SENGUL et al., 2004). Glycoalkaloids are present as alpha-solanine and alpha-chaconine in marginal tuber layers. However, with the increased amassing of the compounds, significant economic losses coupled with food safety hazards are observed. Presently, high glycoalkaloids (GA) intake is considered as grave food safety concern and with the increasing demand for fresh and processed potatoes the threat has increased manifold (PERCIVAL, 1999). Excessive glycoalkaloids accumulation leaves a bitter taste, if the concentration exceeds a specific level, with upper safe intake limit for a human is 20 mg 100 g<sup>-1</sup> f.w (NEMA et al., 2008). Excessive glycoalkaloids intake results in diarrhea, vomiting, fever, rapid pulse, colic pain, low blood pressure, gastroenteritis, and neurological disorders (SLANINA, 1990). Although Photo-induced chlorophyll formation in potatoes is not a serious threat for human body, but green potatoes appear to be highly unattractive in comparison to normal red skinned or white skinned potatoes. The unappealing green color of the potatoes reduce their market value and according to research carried out by British potato council, £ 6 million loss has been borne by the grower due to its green pigmentation (ANON., 1998). Changes in the quality attributes of potato tubers under different colored light sources have been an important point of interests for the retailers. The present study was designed to identify the best light source along with the transition in the vital attributes of potato variety 'Lady Rosetta' at ambient temperature storage.

### Materials and methods

Potato variety 'Lady Rosetta' was harvested from Potato Research Institute, Sahiwal (Punjab, Pakistan). The experimental material was shifted to the Postharvest Technology Laboratory, Department of Food Technology PMAS-Arid Agriculture University Rawalpindi, Pakistan. Potatoes were washed, sorted and graded into the homogenous lot before they were subjected to the different analytical trials. The selected tubers were cured for one week at a temperature between 15-20 °C.

Potato tubers were placed under different light sources in specially designed cabinets. The trial was divided into the following set of treatments:

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T<sub>1</sub> = Blue light (BL)  
T<sub>3</sub> = Green light (GL)  
T<sub>5</sub> = Red light (RL)

T<sub>2</sub> = Fluorescent light (FL)  
T<sub>4</sub> = Mercury Light (ML)  
T<sub>6</sub> = Dark (D)

Potatoes were placed under the lamp of 20 W of different light sources maintained at a distance of 1 m during the complete storage duration (27 days) except in T<sub>6</sub>. All the tubers were barred exposed to different light sources and rotated at 24 hours interval to ensure maximum skin exposure. 1 kg of potato tubers was placed in each replication, and 3 kg tubers were maintained in each treatment for per day analysis. In total, 30 kg of potatoes were left in each treatment and were subsequently subjected to different physicochemical analyses at three days interval. All the potatoes were stored at temperature and relative humidity maintained around  $25 \pm 2$  °C and  $70 \pm 5$  % respectively before being subjected to different analytical estimations.

**Glucose:** Glucose estimation was carried out by glucose test strips imported from Snack Food Association, (Arlington, Virginia USA) along with the color chart expressing glucose percentage. The test strip color change was correlated with the color chart, and the values were expressed in percentage. The tests were conducted in triplicate.

**Total sugar:** Lane and Eynon titration method using Fehling's solution was employed for the estimation of reducing sugar (RS), non-reducing sugar (NRS) and total sugars (TS) contents as reported in AOAC (1990) method no. 925.35. Ten grams sample was diluted with 100 ml water, stirred thoroughly to dissolve all suspended particles, subsequently filtered in 250 ml volumetric flask. 100 ml of prepared solution was transferred into conical flask along with 10 ml of diluted HCl and boiled for 5 minutes. The resultant solution was cooled and neutralized with 10 % NaOH and made up to volume in 250 ml volumetric flask. The solution was titrated against Fehling's solution, and readings were recorded up to brick red end point. The readings were calculated as under:

Total sugar (%) =  $4.95 \text{ (Factor)} \times 250 \text{ (Dilution)} \times 2.5 / \text{Weight of sample} \times \text{Titre} \times 10 \times 100$

**Starch:** Starch estimation was carried out by making the tuber sugar free by the repeated extraction with 80 % isopropanol. Tubers were dried at 70 °C and the starch was hydrolyzed by 60 % perchloric acid. The glucose was estimated spectrophotometrically at 620 nm by using anthrone reagent as described by KUMAR et al. (2005).

**Ascorbic Acid:** Ascorbic acid (AA) estimation was carried out by the titrimetric method by employing 2, 6, dichlorophenol indophenol dye (redox dye) as explained in AOAC (1990) method no. 967.21. 10 g representative sample was taken in a beaker and made up to volume with 100 ml 3 % phosphoric acid and filtered. 10 ml of filtrate was titrated with the standard dye solution till pink end point. The ascorbic acid contents were quantified as under:

AA (mg 100 g<sup>-1</sup> f.w) =  $\text{Dye factor} \times \text{Titration} \times \text{Volume made up} / \text{Weight of sample} \times \text{Volume of filtrate} \times 100$

**Dye standardization:** 5 ml of standard ascorbic acid solution was diluted with 5 ml of metaphosphoric acid (3 %) and titrated with dye solution till pink color endures for 10 seconds. Dye factor was estimated (mg AA / ml of dye) as:  $\text{Dye Factor (D.F)} = 0.5 / \text{Titration}$ .

**Chlorophyll:** Chlorophyll extraction from different tuber samples was carried out by spectrophotometric grade 99.5 % acetone (Sigma-Aldrich) and subsequent quantification was done in spectrophotometer (CE-2021, 2000 series CECIL Instruments Cambridge, England) as illustrated by PERCIVAL (1999). 5 g representative (selected

from each side of potato tuber) lyophilized tissues were ground to a fine powder with the help of mortar and pestle. The sample was transferred to test tubes followed by extraction with 10 ml of acetone. The extract was vortexed then stored at 4 °C for 24-72 hours. After storage, chilled extracts were again vortexed and centrifuged for 15 min at around  $2500 \times g$ . The supernatant was collected for chlorophyll determination.

Chlorophyll content was measured in 1 cm cuvettes at A<sub>647</sub> and A<sub>664.5</sub> using Spectrophotometer (CE-2021, 2000 series CECIL Instruments Cambridge, England). Total chlorophyll concentrations were expressed as mg 100 g<sup>-1</sup> d.w from the following equation:

Total Chlorophyll =  $17.90 \text{ (A647)} + 8.08 \text{ (A664.5)}$

**Total glycoalkaloids:** The total glycoalkaloids (TGA) determination was carried out by the method described by GRUNENFELDER et al. (2006). Ground lyophilized potato tissue (500 mg) was extracted in 10 ml of 80 % ethanol at 85-90 °C for 25 minutes. The extract was filtered and reduced to 3-5 ml on rotary evaporator at 50 °C. Each extract was rinsed twice with 3 ml of 10 % (v/v) acetic acid and then centrifuged at  $10,000 \times g$  for 30 minutes at 10 °C. The pH of the supernatants was adjusted at 9.0 with NH<sub>4</sub>OH. The extract was re-fluxed at 70 °C for 25 minutes followed by overnight storage at 4 °C temperature. The extract was similarly centrifuged as earlier, after discarding the supernatants the resulting pellets were dissolved in 0.5 ml of 7 % (v/v) phosphoric acid and stored at -20 °C. The total glycoalkaloids were estimated by adding 200 µL of extract in 1 ml of 0.03 % (w/v) in concentrated phosphoric acid. The contents were allowed to settle for 20 minutes, and absorbance was measured at 600 nm. TGA concentrations were quantified based on  $\alpha$ -solanine (Sigma-Aldrich) standard curve using a CE-2021, Spectrophotometer (CECIL Instruments Cambridge, England) and expressed as mg TGA 100 g<sup>-1</sup> d.w.

**Total phenolic contents:** Total phenolic contents (TPC) estimated as Gallic Acid Equivalent (GAE) were carried out by Folin-Ciocalteu (FC) assay as explained by LACHMANN et al. (2008) with few modifications. Tubers randomly selected were freeze dried and then extracted with 80 % ethanol. 2 g extract was quantitatively converted into 100 ml volumetric flask and adjusted with 80 % ethanol. In 5 ml of the sample slightly diluted with distilled water, 2.5 ml of FC and 7.5 ml of 20 % solution of sodium carbonate were added. Contents were allowed to settle for 2 hours and absorbance was measured at 765 nm using a CE-2021, Spectrophotometer (CECIL Instruments Cambridge, England). Total phenolic contents were quantified by standard calibration curve derived from the absorbance of known gallic acid concentration (10-100 ppm). Results were articulated as mg GAE 100 g<sup>-1</sup> d.w.

**Radical scavenging activity (RSA):** Antioxidant activity was measured as radical scavenging activity (RSA) using the method described by SINGH and RAJINI (2004) that involves electron transfer reaction based assay by employing free radical 2, 2-diphenyl-1-picrylhydrazyl (DPPH). Five mg of freeze-dried potato extract was incubated with 1.5 ml of DPPH solution (0.1 mM in 95 % Ethanol). The reaction mixture was properly shaken and allowed to stand for 20 minutes at ambient temperature. The absorbance of the resultant mixture was determined at 517 nm against blank. The radical scavenging activity was determined as a decrease in the absorbance of DPPH using the following equation:

Radical scavenging activity (%) =  $1 - A_{\text{sample } 517 \text{ nm}} / A_{\text{Control } 517 \text{ nm}} \times 100$

**Statistical analysis:** Date obtained as the mean of three replications were statistically analyzed by two-factor factorial in Completely Randomized Design (CRD), and treatments and storage intervals mean comparisons were carried out by Duncan Multiple Range test using M-Stat-C Statistical software as described by STEEL et al. (1997).

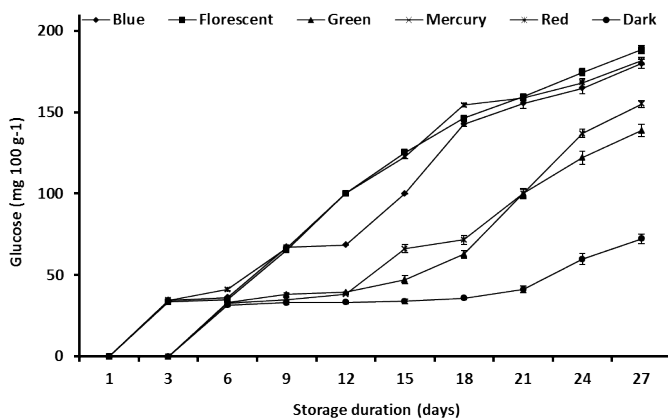
## Results and discussion

The general trend was an increase in glucose contents in all treatments except under dark storage. The treatment means exhibited a maximum increase in fluorescent and red lights and were found at par statistically ( $\alpha=0.05$ ). Minimum glucose retention was demonstrated in dark followed by green and mercury lights. Storage interval means showed minimum glucose contents at the start and maximum at the end of storage period. The interaction between treatments and storage intervals revealed a significant increase in glucose contents during the last week of storage under blue, fluorescent and red lights (Fig. 1). The increase in glucose contents in tubers initiated early under blue, fluorescent and red illuminations and remained two folds than the rest of treatments by the end of 3<sup>rd</sup> week. Green and mercury lights retained moderate increase in glucose contents during most of the storage period. Glucose contents recorded at the end of storage in the dark were found lower than that recorded in fluorescent and red lights by the end of 2<sup>nd</sup> week and found lowest throughout the storage period.

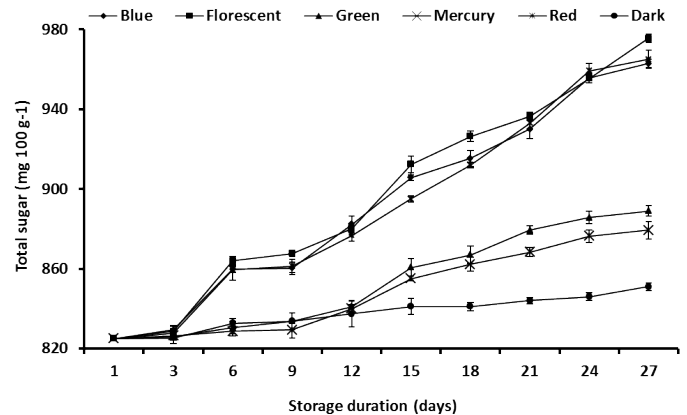
The glucose contents accumulation in potato tubers is associated with the starch hydrolysis during the storage period (SONNEWALD, 2001) and accelerated during tuber stress due to exposure to high energy illuminations (PERCIVAL, 1993). The greater increase in glucose contents during storage under fluorescent, red and blue lights as compared to other treatments might be due to the increased relative degradation of starch contents. The results were also in close confirmation with the findings of CHEN and SETTER (2003) who reported decreased glucose contents in potato tubers under dark storage.

Total sugar accumulation in potato tubers under different illuminations progressively increased during storage. This increase was found in consistence with the trend observed in glucose contents. The treatment means showed maximum sugar accumulation in fluorescent followed by storage under blue and red lights ( $\alpha=0.05$ ). Storage interval means showed a non-significant increase in sugar content during 1<sup>st</sup> week followed by a prominent increase during the rest of storage period. The interaction between treatments and storage intervals showed maximum sugar accumulation under fluorescent light while minimum estimated in dark at the end of the trial (Fig. 2). In general, total sugar increased under all illuminations, however, the increase was highly significant under fluorescent, blue and red lights. In contrast, a steady increase was observed under mercury and green lights. Storage under dark at the end of storage period retained lowest sugar contents than that estimated under all other illuminations. In terms of their sugar accumulation blue and red illumination were found same during most of the storage period.

Continuous exposure of potato tubers to different light sources caused



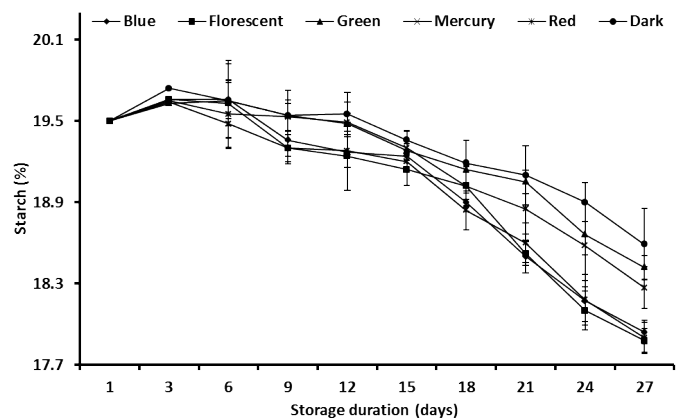
**Fig. 1:** Effect of different light sources on glucose. Vertical bars show  $\pm$ SE of means ( $n=3$ ). The interaction between storage duration and light sources was significantly different at  $p \leq 0.05$ .



**Fig. 2:** Effect of different light sources on total sugar. Vertical bars show  $\pm$ SE of means ( $n=3$ ). The interaction between storage duration and light sources was significantly different at  $p \leq 0.05$ .

sugar accumulation due to starch hydrolysis mediated through tuber stress (PERCIVAL, 1999). The initial increase in sugar contents in response to different illuminations during storage has also been reported by OLSON (1996). DALE et al. (1993) reported elevated sugar contents in potato exposed to continuous illumination as compared to those placed under dark. The moderate sugar contents identified under green and mercury lights might be due to lesser starch hydrolysis owing to their low energy spectrums, which have also been confirmed by NEMA et al. (2008).

Data related to starch contents in response to different illumination revealed non-significant initial increase followed by a progressive decline with the increase in storage period. The treatment means showed minimum starch contents in blue, fluorescent and red lights and were found similar ( $\alpha=0.05$ ). Dark storage retained maximum starch contents at the end of storage followed by green and red lights. The storage interval means showed maximum starch content during 1<sup>st</sup> week storage and then declined significantly by the end of storage period. The interaction between treatments and storage intervals showed minimum starch contents in blue, fluorescent, and red lights on last day storage (Fig. 3). In general, after an initial increase all the treatments experienced starch depletion in response to different illuminations. However, the decrease was highly prominent in red (17.90 %), blue (17.94 %), and fluorescent (18.10 %) lights as compared to other treatments. The minimum decline in starch contents was reported in the dark (18.59 %) followed by green (18.42 %) and mer-



**Fig. 3:** Effect of different light sources on starch (%). Vertical bars show  $\pm$ SE of means ( $n=3$ ). The interaction between storage duration and light sources was significantly different at  $p \leq 0.05$ .

cury (18.27%) illuminations at the end of storage.

The initial increase in starch contents might be due to the tendency of freshly cure potato to accumulate dry matter primarily in the form of starch (KAUL et al., 2010). The metabolism of carbohydrate contents during post-harvest storage is very important both in table and processing potato varieties (HERRMAN et al., 1996). The quality of potato tubers keeps on changing due to depletion of starch and formation of corresponding sugars during storage (NOURIAN et al., 2003). NEMA et al. (2008) reported that continuous exposure of tuber to high energy wavelengths cause physiological stress characterized by increased rate of respiration followed by starch depletion. Maximum starch depletion in potato under different high energy illuminations (fluorescent, blue and red) during the present study confirmed the findings reported above. The general decline in starch content in different treatments might be attributed to the consumption of respiratory substrate (starch) during post-harvest storage which has also been reported by ABBASI et al. (2015).

The general trend showed reduction in ascorbic acid (AA) contents in response to different illuminations during the storage time. The treatment means showed a significant difference between them with maximum and minimum AA retention in dark and fluorescent light, respectively ( $\alpha=0.05$ ). The storage interval means showed a significant difference in AA contents with maximum retention at the start and minimum recorded at the end of the trial. The interaction between treatments and storage intervals showed appreciable retention of AA in dark followed by green during most of the storage period. Significant reduction in AA contents was observed in fluorescent and red lights after one-week illumination (Fig. 4). In the present study, exposure of potato tubers to different illuminations caused a significant reduction in AA. The reduction was highly significant in fluorescent light after mid storage i.e. 21.97 mg 100 g<sup>-1</sup> which lasted up to 17.8 mg 100 g<sup>-1</sup> by the end of one-month storage. By the end of one-month storage tubers, exposure to blue and red lights retained 19.13 mg 100 g<sup>-1</sup> and 19.73 mg 100 g<sup>-1</sup> AA contents, respectively. Moderate reduction of AA contents also reported in the case of green (21.70 mg 100 g<sup>-1</sup>) and mercury (21.40 mg 100 g<sup>-1</sup>) illuminations during the same storage period. Dark storage of potato retained maximum AA contents and the eventual decline observed was only around 22.37 mg 100 g<sup>-1</sup>.

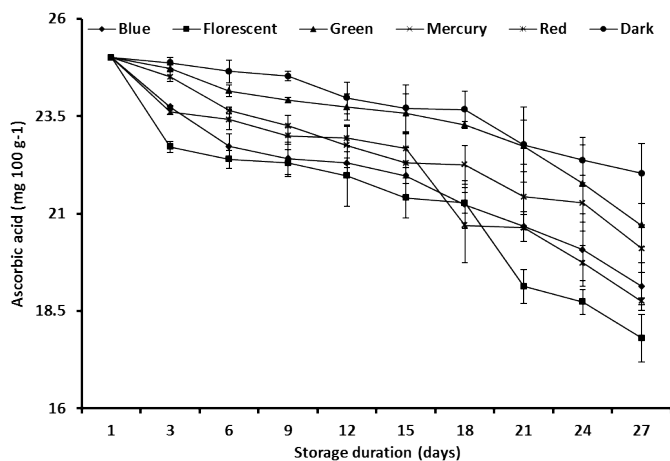
Ascorbic acid is considered as important dietary antioxidant vitamin and known to decline during post-harvest storage period in fruits and vegetables (LEE and KADER, 2000) due to oxidation (PIGA et al., 2002), photodegradation (LESKOVA et al., 2006) or utilization as a respiratory substrate (KADER, 2002). Owing to its high degree of sen-

sitivity it is considered as an imperative index of quality in fruits and vegetable during storage and food processing (OZKAN et al., 2004). In addition, AA depletion has been associated with reduced nutritional quality; therefore their assured stability during storage has been a major concern of the postharvest technologists (ABBASI et al., 2016 a). DALE et al. (2003) reported that AA contents decrease in horticultural products due to light exposure, heat; low relative humidity and prolonged storage time, hence, are critical considerations in optimizing suitable post-harvest storage conditions. Similar results were reported in the present study by maximum retention of AA in dark storage as compared to different illuminations.

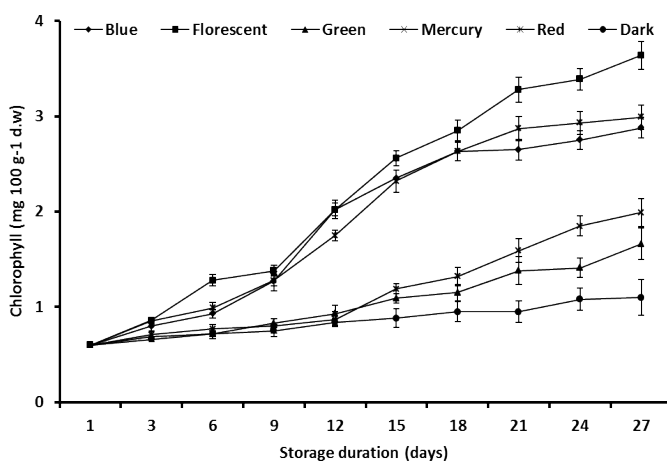
Chlorophyll contents continue to increase significantly during the storage time in response to different light exposures. The treatment means showed maximum chlorophyll accumulation under fluorescent followed by red and blue lights ( $\alpha=0.05$ ). Considerable chlorophyll contents were estimated in red followed by restrained contents identified under green and mercury lights. Chlorophyll contents remained at a minimum level under dark storage. The interaction between treatments and storage intervals demonstrated minimum contents witnessed in most of the treatments by the end of 1<sup>st</sup> week storage, whereas maximum contents were estimated in blue, fluorescent and red lights by the end of last week (Fig. 5).

Chlorophyll contents increased progressively under fluorescent, blue and red illuminations and showed steady increase under dark during the storage period. The contents started to increase in high energy illuminations within 1<sup>st</sup> week of storage particularly in fluorescent light, i.e. 1.283 mg 100 g<sup>-1</sup>. In contrast, lowest chlorophyll contents were estimated in the dark i.e. 0.721 mg 100 g<sup>-1</sup> during the same storage period. A similar trend continued with maximum contents that were recorded under fluorescent light i.e. 3.64 mg 100 g<sup>-1</sup>. This significant linear increase in the chlorophyll contents was more than six folds over the complete storage period under fluorescent light. The response of potato to exposure to red (3.219 mg 100 g<sup>-1</sup>) and blue (3.231 mg 100 g<sup>-1</sup>) illuminations accumulated considerable chlorophyll contents as compared to mercury (1.99 mg 100 g<sup>-1</sup>) and green (1.66 mg 100 g<sup>-1</sup>) lights at the end of storage. In general, all different kind of illuminations caused an increase in chlorophyll contents at erratic pace with no indication of termination during the complete trail.

Exposure of potato tubers in response to light caused the formation of chlorophyll in cortical parenchyma due to the conversion of amyloplast into chloroplast (PAVLISTA, 2001). The extent of greening in retail outlets emphasizing the development and realization of the appropriate light source to maintain desirable quality attributes in



**Fig. 4:** Effect of different light source on ascorbic acid. Vertical bars show  $\pm$ SE of means ( $n=3$ ). Interaction between storage duration and light sources was significantly different at  $p \leq 0.05$ .



**Fig. 5:** Effect of different light sources on chlorophyll. Vertical bars show  $\pm$ SE of means ( $n=3$ ). The interaction between storage duration and light sources was significantly different at  $p \leq 0.05$ .



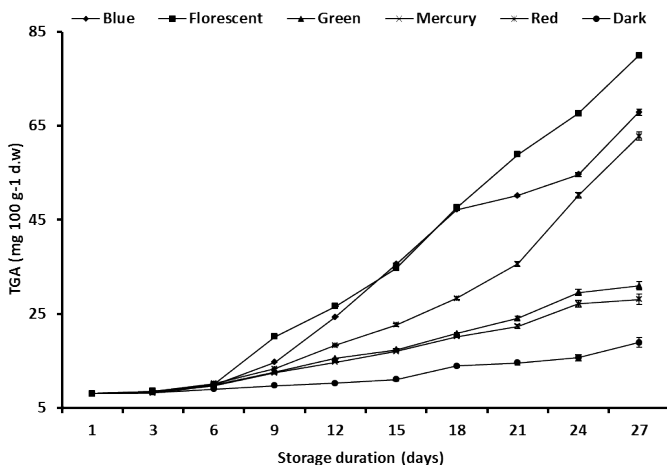
potato tubers. PERCIVAL (1999) compared the response of different tuber varieties to various light sources and reported irrespective of variety maximum chlorophyll accumulation under fluorescent and sodium illuminations as compared to mercury light and dark. GRUNENFELDER et al. (2006) exposed different colored potato varieties to fluorescent lights of similar intensity and found discoloration of periderm in all of them due to a significant increase in chlorophyll contents. The present study demonstrated significant chlorophyll accumulation in potato tubers due to various illuminations. Our results concluded that the replacement of fluorescent light with green or mercury illuminations in retail displays, might cause a reduction in potato greening as also reported by researchers above. Dark potato storage demonstrated appreciable tuber quality due to minimum chlorophyll accumulation and thus might be recommended for prolonged tuber storage, which has also been concluded by different researchers like NEMA et al. (2008) and MACHADO et al. (2007).

Data related to total glycoalkaloids (TGA) showed progressive increase under different illuminations during storage. The treatment means showed a significant difference between their TGA contents with maximum retention in fluorescent followed by blue and red lights, while minimum TGA contents were identified under dark storage ( $\alpha=0.05$ ). The storage interval means showed minimum TGA contents during 1<sup>st</sup> week and then progressively increased until the end of storage. A significant interaction was observed between treatments and storage intervals with highest TGA contents estimated in fluorescent during last week (Fig. 6). The TGA contents increased throughout the storage period irrespective of treatments, however, the rate of increase in TGA contents was higher in fluorescent, blue and red light illuminations. The increase in TGA contents under fluorescent light was maximum (70.40 mg 100 g<sup>-1</sup> d.w) and estimated around 8-folds as compared to the 2.5-folds increase in the dark by the end of storage period. The increase in TGA contents under fluorescent illumination at the end of storage surpassed the safe limits described for human intake i.e. 20 mg 100 g<sup>-1</sup> f.w (MENSINGA et al., 2005). In general, percentage increase in TGA within different storage interval was found highest in last week. Minimum TGA accumulation was identified in the dark (18.90 mg 100 g<sup>-1</sup> d.w) followed by mercury (28.03 mg 100 g<sup>-1</sup> d.w) and green (30.93 mg 100 g<sup>-1</sup> d.w) illuminations.

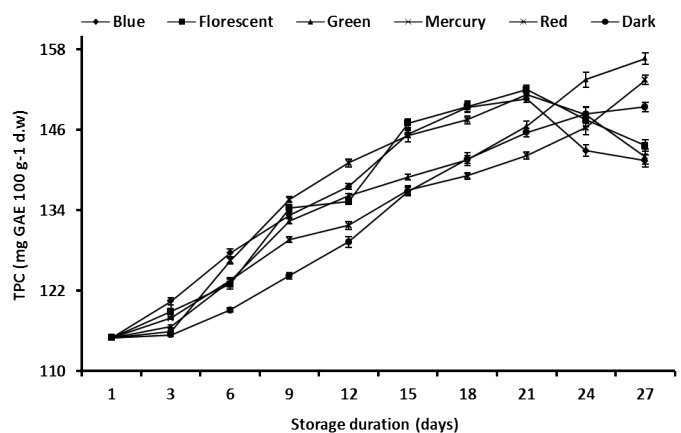
TGA contents estimated in the present study regarding solanine equivalent are affected by different illuminations and are also associated with the elevated chlorophyll contents. GRUNENFELDER et al. (2006) studied the increase in TGA and chlorophyll contents under fluorescent light and concluded parallel but independent de-

velopment of both compounds. MACHADO et al. (2007) compared TGA accumulation in potato tubers under different illuminations during postharvest storage. She found maximum and minimum TGA contents under fluorescent light and dark respectively as also observed in the present study. Another investigation carried out by PERCIVAL et al. (1999) observed light-induced TGA accumulation in potato tubers under four different illuminations. He declared maximum contents under fluorescent and sodium lights and minimum under dark. Our results in the present study also confirmed the previous finding as steady TGA contents in the dark as compared to significant increase under fluorescent light. The trial also exhibited a parallel association between chlorophyll and glycoalkaloids accumulations in potato tubers. The process is however found independent due to increased TGA contents in blue to red and green to mercury lights having less corresponding chlorophyll contents during the same storage period.

Total phenolic contents (TPC) increased steadily during the storage period in response to different illuminations. However, the increase is followed by a considerable decline in blue, fluorescent and red lights. In general non-significant difference in treatment means was observed except in mercury and dark storage ( $\alpha=0.05$ ). The storage interval means, however, showed significant difference with maximum and minimum TPC identified at the end and the start of the experiment. Highly significant interaction was observed between treatments and storage intervals after the mid storage period (Fig. 7). Total phenolic contents increased during the start of storage in all the treatments, and the initial rise was found independent of different illuminations. In general non-significant difference was observed in most of the treatments till 9<sup>th</sup> day storage. TPC contents significantly increased in all the treatments by the end of 2<sup>nd</sup> week storage, which was followed by progressive decline in fluorescent, blue and red illuminations during the last week of storage. TPC increased continuously under green, mercury and dark storage with no sign of cessation during the storage period. However, the rate of TPC increase during the 1<sup>st</sup> half of storage was found slower as compared to high energy illuminations (blue, fluorescent and red lights). Total phenolic contents showed varied retention under different illuminations during the storage period. Light is considered as an important factor causing the biosynthesis of phenolic compounds facilitated by the activity of phenylalanine ammonia-lyase enzymes (LEWIS et al., 1998). In addition, it is also known to initiate the anthocyanin and chlorogenic biosynthesis pathways contributing to the total phenolic contents in potato tubers (GRIFFITHS, 1995). The swift initial increase in TPC under different light sources and steady TPC



**Fig. 6:** Effect of different light sources on total glycoalkaloids. Vertical bars show  $\pm$ SE of means ( $n=3$ ). The interaction between storage duration and light sources was significantly different at  $p \leq 0.05$ .

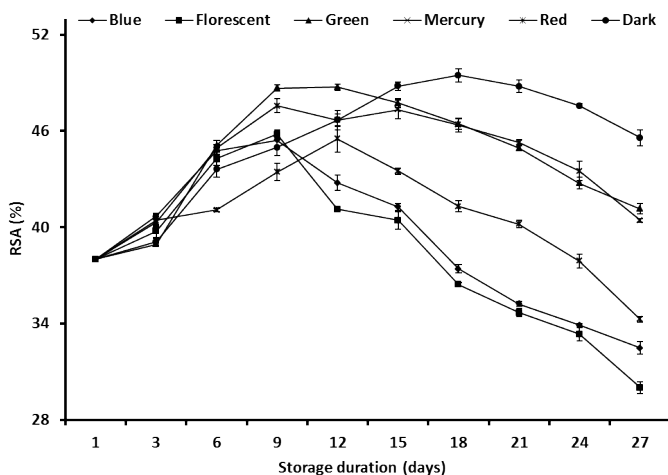


**Fig. 7:** Effect of different light sources on total phenolic content. Vertical bars show  $\pm$ SE of means ( $n=3$ ). Interaction between storage duration and light sources was significantly different at  $p \leq 0.05$ .

under dark partially confirmed the findings reported by different researchers above. These results, however, negated the investigation reported by REYES and ZEVALLOS (2003) who reported no considerable effect of light on the TPC accumulation in purple-fleshed potato tubers. The possible reason might be due to the varietal difference and lack of their comparative study under different illuminations. Tubers placed under green and mercury lights retained appreciable TPC at the end of storage probably due to lack of tuber stress and moderate respiration rate. The decline in TPC contents under high energy illuminations like fluorescent and blue at the end of storage might be attributed to the tuber stress due to high metabolic rate, increased rate of respiration causing an eventual decline in TPC contents.

Radical scavenging activity (RSA) estimated as % inhibition of DPPH showed slight initial increase followed by gradual decrease under all illuminations except in the dark. Treatment means showed that dark storage maintained maximum activity followed by green and mercury lights, while minimum RSA activity was shown under fluorescent followed by blue lights ( $\alpha=0.05$ ). Storage interval means showed maximum activity till 2<sup>nd</sup> week and then steadily declined till the end. The interaction between treatments and storage intervals was initially found less significant and then became highly significant by the end of storage period. The maximum activity was expressed in green and dark during 3<sup>rd</sup> and 2<sup>nd</sup> week storages, respectively (Fig. 8). In general RSA activity exhibited initial increase till mid storage period and finally declined to form a sort of parabolic curve. However, the rate of increase and decrease in activity was considerably affected by different illuminations. Radical scavenging activity increased during the first week and attained maximum by the second week in blue (45.43%), fluorescent (45.80%) and red (47.57%) lights followed by progressive decline afterward. The trend remained same at variable pace in green (48.73%), mercury (47.33%) and red (49.47%) where they showed maximum activity by the end of the third week followed by a steady decline onwards. Overall results revealed maximum retention of RSA in dark storage (45.57%) followed by green (43.60%) and mercury (42.77%) lights at the end of storage period.

It is eventually observed that, except in dark storage, potato tubers placed under different illuminations lost considerable RSA activity after the completion of storage period. RSA activity corresponds to the antioxidant potential retained by the potato tubers and is associated with the presence of different functional components, such as phenolic compounds, carotenoids, ascorbic acid and tocopherols



**Fig. 8:** Effect of different light sources on radical scavenging activity (%). Vertical bars show  $\pm$ SE of means ( $n=3$ ). The interaction between storage duration and light sources was significantly different at  $p \leq 0.05$ .

(ABBASI et al., 2016 b). In the present study, storage under different illuminations conferred diverse effects on these antioxidant components as attributed to the parallel accumulation of phenolics and depletion of ascorbic acids. The prolonged exposure of potato tubers to high energy illuminations might confer tuber stress consequently resulted in the loss of phenolic substrate due to the increased polyphenol oxidase activity (BRYANT, 2004). The significant retention of RSA activity at the end of storage under dark as compared to different illuminations might be due to the appreciable retention of dietary antioxidants, such as ascorbic acid, total phenolic contents etc. HEJTMANKOVA et al. (2009) and LACHMANN et al. (2008) have also expressed this significant correlation between RSA activity and these functional components.

## Conclusion

It is concluded that during thirty day storage ( $25 \pm 2^\circ\text{C}$ ) under different illuminations (blue, fluorescent, green, mercury, red, dark), potato tubers presented variable response regarding their investigated quality parameters. Best results were identified in potato tubers kept under dark with minimum loss of quality parameters. Storage under different illuminations showed maximum retention of quality parameters in green and mercury lights with better storage life. Tuber stability was found highly susceptible to fluorescent light with least retentions of quality parameters. Storage under red and blue light also resulted in decreased storage life with the loss of quality attributes studied.

## References


- ABBASI, K.S., MASUD, T., QAYYUM, A., KHAN, S.U., AHMAD, A., MEHMOOD, A., FARID, A., JENKS, M.A., 2016a: Transition in tuber quality attributes of potato (*Solanum tuberosum* L.) under different packaging systems during storage. J. Appl. Bot. Food Qual. 89, 142-149.
- ABBASI, K.S., MASUD, T., QAYYUM, A., KHAN, S.U., ABBAS, S., JENKS, M.A., 2016b: Storage stability of potato variety Lady Rosetta under comparative temperature regimes. Sains Malay. 45, 677-688.
- ABBASI, K.S., MASUD, T., ALI, S., KHAN, S.U., MAHMOOD, T., QAYYUM, A., 2015: Sugar-starch metabolism and antioxidant potential in potato tubers in response to different antisprouting agents during storage. Potato Res. 58, 361-375, doi: 10.1007/s11540-015-9306-4.
- ANON., 1998: Potato industry digests, British Potato Council. U.K.
- AOAC (Association of Analytical Chemists), 1990: Official Methods of Analysis. 15<sup>th</sup> ed., Virginia 22201, Arlington, USA.
- BRYANT, P., 2004: Optimising the postharvest management of Lychee (*Litchi chinensis* Sonn.). A study of mechanical injury and desiccation. Ph.D Thesis. University of Sydney.
- BURLINGAME, B., MOUILLE, B., CHARRONDIERE, R., 2009: Nutrients, bioactive non-nutrients and anti-nutrients in potatoes – A Critical Review. J. Food Comp. Anal. 22, 494-502. doi: 10.1016/j.jfca.2009.09.001.
- CHEN, C.T., SETTER, T.L., 2003: Response of potato tuber cell division and growth to shade and elevated  $\text{CO}_2$ . Ann. Bot. 91, 373-381. doi: 10.1093/aob/mcg031.
- CIP (International Potato Center), 1997: Annual Report, 239-264.
- DALE, M.B.F., GRIFFITHS, D.W., BAIN, H., TODD, D., 1993: Glycoalkaloid increase in *Solanum tuberosum* on exposure to light. Ann. Appl. Biol. 123, 411-418.
- DALE, M.F.B., GRIFFITHS, D.W., TODD, D.T., 2003: Effects of genotype, environment, and postharvest storage on the total ascorbate content of potato (*Solanum tuberosum*) tubers. J. Agri. Food Chem. 51, 244-248. doi: 10.1021/jf020547s.
- FRIEDMAN, M., 2004: Analysis of biologically active compounds in potatoes (*Solanum tuberosum*), tomatoes (*Lycopersicon esculentum*) and jimson weed (*Datura stramonium*) seeds. J. Chromatogr. A. 1054, 143-155. doi: 10.1016/j.chroma.2004.04.049.

- GRAVOUEILLE, J.M., 1999: Utilization en la alimentacion humana (Use in the human feeding). In: Rouselle, P., Robert, Y., Crosnier, J.C. (eds), *La Patato* (The potato), 459-508. Mundi prensa, Madrid.
- GRIFFITHS, D.W., BAIN, H., DALE, M.F.B., 1995: Photo-induced changes in the total chlorogenic acid content of potato (*Solanum tuberosum*) tubers. *J. Sci. Food Agric.* 68, 105-110.
- GRUNENFELDER, L.A., KNOWLES, L.O., HILLER, L.K., KNOWLES, N.R., 2006: Glycoalkaloid development during greening of fresh market potatoes (*Solanum tuberosum* L.). *J. Agri. Food Chem.* 54, 5847-5854. doi: 10.1021/jf0607359.
- HEJTMANKOVA, K., PIVEC, V., TRNKOVA, E., HAMOUZ, K., LACHMAN, J., 2009: Quality of coloured varieties of potatoes. *Czech. J. Food Sci.* 27, 310-313.
- HERMAN, T.J., LOVE, S.L., SHAFIL, B., DWELLE, R.B., 1996: Chipping performance of three potato cultivars during long term storage at two temperature regimes. *Am. Potato J.* 73, 411-425.
- KADER, A.A., 2002: Recommendations for maintaining postharvest quality. Postharvest Technology Research Information Center. Department of Pomology. University of California. One Shield Ave., Davis, CA, USA.
- KAUL, A.D., KUMAR, P., HOODA, V., SONKUSARE, A., 2010: Biochemical behavior of different cultivars of potato tuber at different storage conditions. National Conference on Computational Instrumentation CSIO Chandigarh, India. 172-176.
- KOLASA, K.M., 1993: The potato and human nutrition. *Am. Potato J.* 70, 375-384. doi: 10.1007/BF02849118.
- KUMAR, D., EZEKIEL, R., SINGH, B., AHMED, I., 2005: Conversion table for specific gravity, dry matter and starch content from under water weight of potatoes grown in North Indian plains. *Potato J.* 32, 79-84.
- LACHMAN, J., HAMOUZ, K., ORSAK, M., PIVEC, V., 2001: Potato glycoalkaloids and their significance in plant protection and nutrition. *Rost. Vyroba* 47, 181-192.
- LACHMANN, J., HAMOUZ, K., ORSAK, M., PIVEC, V., 2000: Potato tubers as a significant source of antioxidants in human nutrition. *Rost.Vyroba* 46, 231-236.
- LACHMANN, J., HAMOUZ, K., ORSAK, M., PIVEC, V., 2008: The influence of flesh colour and growing locality on polyphenolic content and antioxidant activity in potatoes. *Sci. Hort.* 117, 109-114. doi: 10.1016/j.scienta.2008.03.030.
- LEE, S.K., KADER, A.A., 2000: Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol.* 20, 207-220. doi: 10.1016/S0925-5214(00)00133-2.
- LESKOVA, E., KUBIKOVA, J., KOVACIKOVA, E., KOSICKA, M., PORUBSKA, J., HOLCÍKOVÁ, K., 2006: Vitamin losses: Retention during heat treatment and continual changes expressed by mathematical models. *J. Food Comp. Anal.* 19, 252-276. doi: 10.1016/j.jfca.2005.04.014.
- LEWIS, C.E., WALKER, J.R.L., LANCASTER, J.E., SUTTON, K.H., 1998: Determination of anthocyanins, flavonoids and phenolic acids in potatoes. I: Coloured cultivars of *Solanum tuberosum* L. *J. Sci. Food Agric.* 77, 45-57. doi: 10.1002/(SICI)1097-0010(199805)77:1<45::AID-JSFA1>3.0.CO;2-S.
- MACHADO, R.M.D., TOLEDO, M.C.F., GARCIA, L.C., 2007: Effect of light and temperature on the formation of glycoalkaloids in potato tubers. *Food Control* 18, 503-508. doi: 10.1016/j.foodcont.2005.12.008.
- NEMA, P.K., RAMAYA, N., DUNCAN, E., NIRANJAN, K., 2008: Potato Glycoalkaloids: formation and strategies for mitigation- A review. *J. Sci. Food Agric.* 88, 1869-1881. doi: 10.1002/jsfa.3302.
- NOURIAN, F., RAMASWAMY, H.S., KUSHALAPPA, A.C., 2003: Kinetics of quality change associated with the potatoes stored at different temperatures. *LWT-Food Sci. Technol.* 36, 49-65. doi: 10.1016/S0023-6438(02)00174-3.
- OLSSON, K., 1996: Attempts to unveil potato clones disposed to stress induced accumulation of glycoalkaloids in the field. Proceedings of the European Association of Potato Research 13<sup>th</sup> Trien. Conference, Veldhoven, The Netherlands, Abstract Conference Paper, 538.
- OZKAN, M., KIRCA, A.E., CEMERO, B., 2004: Effects of hydrogen peroxide on the stability of ascorbic acid during storage in various fruit juices. *Food Chem.* 8, 591-597. doi: 10.1016/j.foodchem.2004.02.011.
- PAVLISTA, A.D., 2001: Green potatoes: The problem and the solution. Neb. Guide online: G01-1437-A.
- PERCIVAL, G., 1999: Light-induced glycoalkaloid accumulation of potato tubers (*Solanum tuberosum* L.). *J. Sci. Food Agric.* 79, 1305-1310. doi: 10.1002/(SICI)1097-0010(19990715)79:10<1305::AID-JSFA368>3.0.CO;2-R.
- PERCIVAL, G.C., HARRISON, J.A.C., DIXON, G.R., 1993: The influence of temperature on light enhanced glycoalkaloid synthesis in potato. *Ann. Appl. Biol.* 123, 141-153. doi: 10.1111/j.1744-7348.1993.tb04081.x.
- PIGA, A., AGABBIO, M., GAMBELLA, F., NICOLI, M.C., 2002: Retention of antioxidant activity in minimally processed mandarin and Satsuma fruits. *LWT-Food Sci. Technol.* 35, 344-347. doi: 10.1006/ftsl.2001.0877.
- REYES, L.F., ZEVALLOS, L.C., 2003: Wounding stress increases the phenolic content and antioxidant capacity of purple-flesh potatoes (*Solanum tuberosum* L.). *J. Agric. Food Chem.* 51, 5296-5300. doi: 10.1021/jf034213u.
- RYTEL, E., GOLUBOWSKA, G., LISIŃSKA, G., PEKSA, A., ANIOŁOWSKI, K., 2005: Changes in glycoalkaloid and nitrate contents in potatoes during French fries processing. *J. Sci. Food Agric.* 85, 879-882. doi: 10.1002/jsfa.2048.
- SENGUL, M., KELES, F., KELES, M.S., 2004: The effect of storage conditions (temperature, light, time) and variety on the glycoalkaloid content of potato tubers and sprouts. *Food Control* 15, 281-286. doi: 10.1016/S0956-7135(03)00077-X.
- SINGH, N., RAJINI, P.S., 2004: Free radical scavenging activity of an aqueous extract of potato peel. *Food Chem.* 85, 611-616. doi: 10.1016/j.foodchem.2003.07.003.
- SLANINA, P., 1990: Solanine (glycoalkaloids) in potatoes: toxicological evaluation. *Food Chem. Toxicol.* 28, 759-761. doi: 10.1016/0278-6915(90)90074-W.
- SONNEWALD, U., 2001: Control of potato tuber sprouting. *Trends Plant Sci.* 6, 333-335. doi: 10.1016/S1360-1385(01)02020-9.
- STEEL, R.D., TORRIE, J.H., DICKEY, D., 1997: Principle and procedure of statistics. A biometrical approach: 3<sup>rd</sup> Ed. McGraw-Hills Book Co. Inc. New York.
- WALINGO, A., KABIRA, J.N., KIDANEMARIAM, H.M., EWELL, P.T., 1995: Evaluating potato clones under seed and ware storage conditions at Tigoni-Kenya. Proceedings of the Triennial Symposium, International Society for Root Crops (ISTRIC)-AB, Lilongwe, Malawi, 515-579.

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